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AUTHOR	Richards, William D., Jr.
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ABSTRACT

Previous methods for determining the communication structure of organizations work well for small or simple organizations, but are either inadequate or unwieldy for use with large complex organizations. An improved method uses a number of different measures and a series of successive approximations to order the communication matrix such that people who talk to each other are near each other in the matrix, liaison individuals between groups can be identified, and small groups within the organization separated. By using lists of the contacts of each individuals instead of a full matrix with many blank elements, the structure of a large and complex organization can be determined within a realistic amount of computer time. (RH)

AN IMPROVED CONCEPTUALLY-BASED METHOD FOR ANALYSIS OF COMMUNICATION NETWORK STRUCTURES OF LARGE COMPLEX ORGANIZATIONS

William D. Richards, Jr.
Department of Communication
Michigan State University
April, 1971

An increasing amount of interest is being shown in the study of the communication process in complex organizations. To understand any system fully it is necessary to know its structure--especially the way in which the various components are linked together. However, there has been relatively little scientific effort devoted to devising formal methods for the study of communication networks in large complex organizations.

Several methods of analysis have been tried since the earliest publications of Festinger, Jacobson, Seashore, and Weiss, all in the early fifties. Some of these methods work well for small organizations; some work well for simple organizations. None work well for large complex organizations. This limitation has been a major barrier to the analysis of communication network structures.

In the following sections of this paper, some of these early methods will be examined briefly and their shortcomings will be discussed. Then a new method, one that is promising for very large systems will be presented. Finally, a section will be devoted to a discussion of computerized applications of this new method. A sample analysis will be worked out using the algorithms as they are presented.

CRITIQUE OF PRESENTLY USED METHODS

Before discussing the various methods of analysis, it is necessary to discuss the goals of network analysis, as applied to communication networks.

An organization can be thought of as a system. As such, it will have components and connections between them. It is convenient to think of these components as small groups or cliques, composed of people who talk mainly to others in the same group. The connections, then, are those people who talk to people in more than one group. These connectors have been called liaison agents if they do not belong mainly to the groups which they connect. If they do belong to a group and still talk to people in other groups, they are bridge agents. Thus, liaison agents and bridge agents differ in that the former do not belong to primary groups, whereas the latter do. Similarly, a person who talks to no one is an isolate. Most of the definitions presented above were drawn from Jacobson and Seashore, 1951. A graphical representation of these terms is shown in Figure 1.

The preliminary goal of network analysis of complex organizations is to identify groups, liaison agents, bridge agents, and isolates. Only after this is done can dynamic processes relating these components be effectively studied. That is, to study such things as the factors influencing the formation of cliques, the movement of messages, the effectiveness of liaison agents, and so on; it is necessary first to be able to identify the members of cliques and the liaison agents; second, to isolate the relevant variables; and finally to study the effects of these variables on the formation and growth of communication networks.

The simplest method for examining the communication structure of an organization is by constructing sociograms. For every person in the system, a point is put on a sheet of paper. For every instance in which any one person reports that he talks to any other, an arrow is drawn, connecting the points corresponding to this pair of people, and pointing toward the second person's point. After all arrows have been drawn, it is a simple matter to see the structure, if the organization is small and simple and the points happen to fall in the right places. For more than fifty people, the task is difficult. For more than a few hundred, it is practically impossible. (The diagram in Figure 1 is an example of a sociogram.)

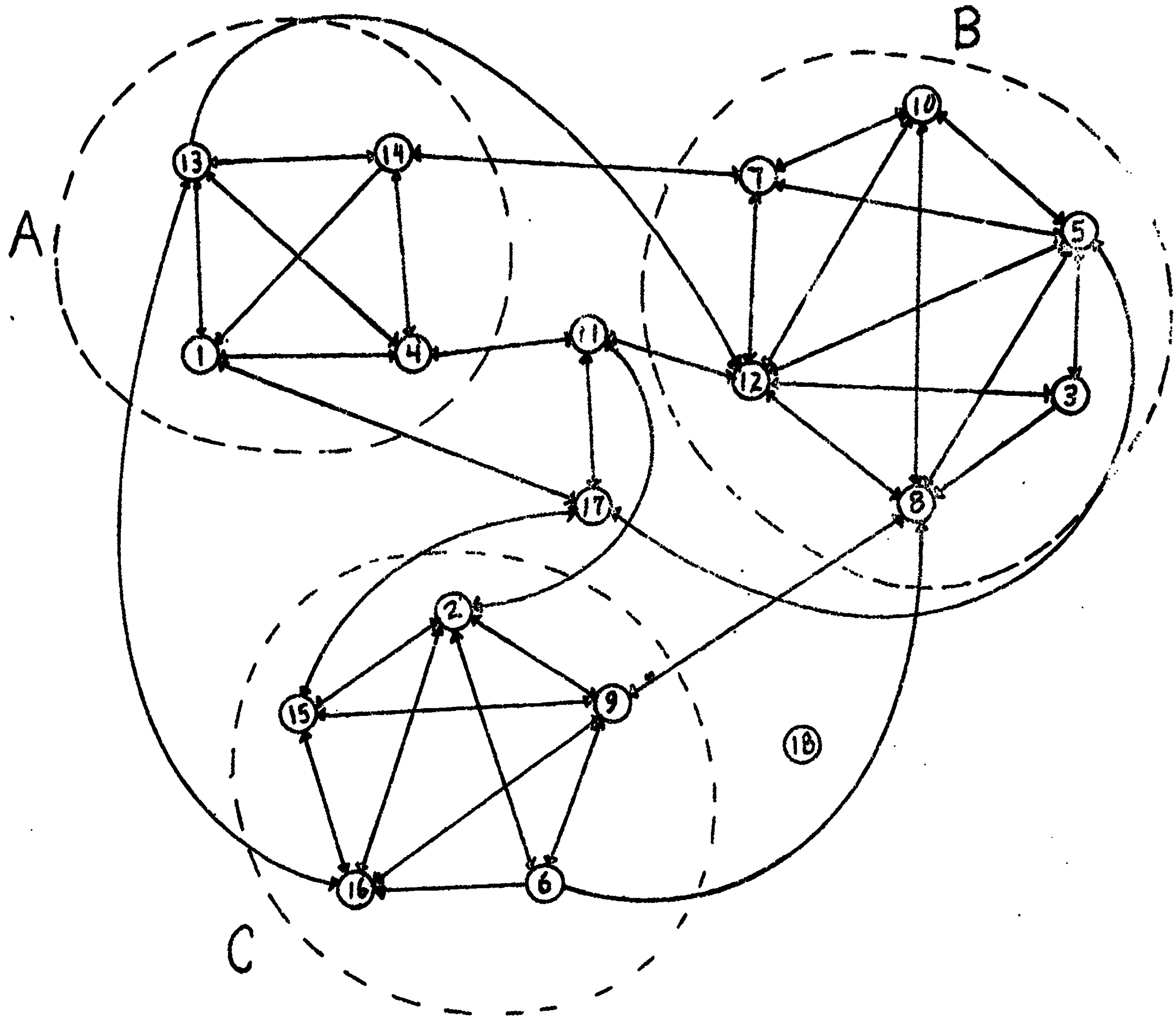


FIGURE 1. THE SOCIOGRAM

IN THE ORGANIZATION SYMBOLIZED BY THIS DIAGRAM THERE ARE THREE CLIQUES, LABELLED "A", "B", AND "C".

THERE ARE ALSO: TWO LIAISON AGENTS — #11 AND #17

ONE ISOLATE, #18

SEVERAL BRIDGE AGENTS, INCLUDING #8, #9, #13, #16, #7, AND SO ON.

A method that seems more promising, if only because of its rigid logical elegance, involves graph theory. Graph theory uses formal concepts, such as points, lines, articulation points, trees, fundamental cut sets, and so on. The fact that organizations of people are not structured by formal rules seems not to bother protagonistis of graph theory. Since the algebra of this theory is not yet sufficiently developed applications of this method become laborious when large numbers of people are involved.

A third method, although not as esthetically pleasing as graph theory, has enjoyed much more attention. This is the matrix algebra method (Festinger, 1949). This method deals with an NxN matrix (binary in its simplest form, but sometimes probabilistic) which is defined by the rule:

$$\left\{\begin{array}{l} aj = 1 \\ aij = 1 \text{ if } iRj \\ \text{else } aij = 0 \end{array}\right\} = Aij$$

The entries in the matrix are often restricted only to those which correspond to reciprocated contacts. (Figure 2 is the binary matrix for the same organization diagrammed in Figure 1.) To determine the structure of the network, the matrix is raised to successive powers. People who have non-zero entries on the main diagonal are considered to be clique members. This method works well, if there is only one clique.

If there are several cliques, a method for determining how many there are and to which one each person belongs must be devised. If any individual belongs to more than one clique, a complicated and laborious process must be initiated, in hopes of deciding what should be done with this person. This method, also, bogs down with large complex organizations. However, most of the processes used are simple and explicitly defined, and thus amendable to computerization. This is useless, though, because very large

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0
2	0	1	0	0	0	1	0	0	1	0	1	0	0	0	1	1	0	0
3	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
4	1	0	0	1	0	0	0	0	0	0	1	0	1	1	0	[illegible]	0	0
5	0	0	1	0	1	0	1	1	0	1	0	1	0	0	0	0	1	0
6	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
7	0	0	0	0	1	0	1	0	0	1	0	1	0	1	0	0	0	0
8	0	0	0	0	1	0	0	1	1	1	0	1	0	0	0	0	0	0
9	0	1	0	0	0	1	0	1	1	0	0	0	0	0	1	1	0	0
10	0	0	0	0	1	0	1	1	0	1	0	1	0	0	0	0	0	0
11	0	1	0	1	0	0	0	0	0	0	1	1	0	0	0	0	1	0
12	0	0	1	0	1	0	1	1	0	1	1	1	0	0	0	0	0	0
13	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0
14	0	0	0	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0
15	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0
16	0	1	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0	0
17	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	1	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

FIGURE 2. THE BINARY MATRIX

THIS IS THE BINARY MATRIX FOR THE ORGANIZATION DIAGRAMMED IN FIGURE 1. IT HAS BEEN RESTRICTED TO INCLUDE ONLY RECIPROCATED CONTACTS. ALSO, 1's HAVE BEEN INSERTED ON THE MAJOR DIAGONAL.

amounts of computer memory are needed to raise the initial matrix to the powers demanded and to store the auxiliary matrices needed. Consequently, this method is impractical for large complex organizations, without incurring unrealistic computer time costs.

Weiss (1956) discusses a hybrid method, utilizing parts of both graph theory and matrix algebra theory. When combined with brute physical manipulation, his method works for large numbers of people, if enough time is available. For this process, the binary matrix described earlier is used as a starting point. Rows and columns of this matrix are painstakingly manipulated until the non-zero entries appear to cluster around the major diagonal (see Figure 3). This is done with the aid of the organization chart for the system whose structure is being studied.

After this re-arrangement, the matrix is often squared, so that liaison agents can be identified and isolated. Although this method usually works, the process is extremely time-consuming; and, since it requires many subjective decisions to be made, it is not suited to be programmed for a computer. (This writer is aware of only three instances in which this method was used. They are: Weiss, 1956; Schwartz, 1968; and MacDonald, 1970).

Other methods have been tried, and have been found wanting for various reasons. One of these involved the computerized application of factor analysis routines to the original matrix (Wackman, 1967). These routines are extremely slow for matrices numbering up to one hundred people; for larger groups they are not readily available. Also, the resultant factors and loadings emerging from different rotations are of doubtful correspondence to any of the desired components of network structure.

1	1												
1	1		1										
		1	1										
	1	1	1										
				1	1		1	1	1				
				1	1	1	1		1				
					1	1	1	1	1				
				1	1	1	1		1				
				1		1		1	1				
				1	1	1	1	1	1				
										1		1	1
											1	1	1
										1	1	1	
										1	1		1

FIGURE 3. THE MANIPULATED MATRIX

THIS IS THE END RESULT OF WEISS' MATRIX MANIPULATION PROCESS. IN THIS FINAL MATRIX, MEMBERS OF THE GROUP ARE LISTED ADJACENT TO ONE ANOTHER.

(WEISS, 1956; P. 104)

It is the author's belief that the use of any of the methods described failed primarily because they were not conceptually suited for the analysis of large or complex organizations. The fact that some of them apparently work for small simple organizations is unfortunate; for this has encouraged further attempts to apply them to larger systems, where they inevitably fail. In the next section a theoretical basis for direct, conceptually simple process will be presented.

CONCEPTUAL BASIS FOR AN ALTERNATIVE METHOD

The theory for the method to be presented in this paper is based on the definitions of _groups_, _liaison agents_, _bridge agents_, _isolates_, and _membership_. Therefore it would be appropriate to review these definitions here (Weiss, 1956).

A _group_ or _clique_ is a set of people who talk more with each other than with people outside their group.

A person is a _member_ of a group if over half of his communications are with people in that same group.

A person is a _liaison agent_ if most of his communications are not with members of any one group, and if he has at least three contacts.

A person is a _bridge agent_ if he belongs to a group but talks to at least one person in another group.

A person is an _isolate_ if he talks to no one.

The goals of network analysis, as discussed in this paper, are to identify these components in an organization.

The data used as a starting point for this analysis are in the form of sociometric communication reports. People are asked to list the people they talk to. These data are usually modified by the elimination of _non_-reciprocated contacts. After collecting the data, there are three major steps in the method of analysis to be presented: 1) ordering the communication matrix, so that people who talk to each other are near each other in the matrix; 2) identifying the liaison individuals; and 3) separating the small groups within the organization. (These steps are very similar to those used by Weiss in his method. The means of performing them, however, are quite different.)

ORDERING THE MATRIX

From the definitions, it follows that the distinguishing behavior of a person in specific group is that while he talks mainly to people in that group, non members don't. Similarly, the behavior which makes a group member similar to other members of the same group is that both talk mainly to the same people (see Figure 4). If a formal rule for expressing this "differentness" or "sameness" in mathematical terms is used, the structural sorting process can be specified exactly enough to be done with only objective decisions.

Another statement that can be made about the relationship between a group member and another member of that group is that, since they both belong to the same group, they probably talk to the same people. That is, there will be many shared contacts, or two-step links between them. This will usually not be the case for two people not in the same group.

To put this concept into mathematical terms is relatively simple: Each person is assigned a unique subject number. Then for each person in the sample, there will be a list or distribution of contactee subject numbers (Figure 5a). To see whether or not two people have the same contactees, the distributions of each person's contactee's subject numbers are

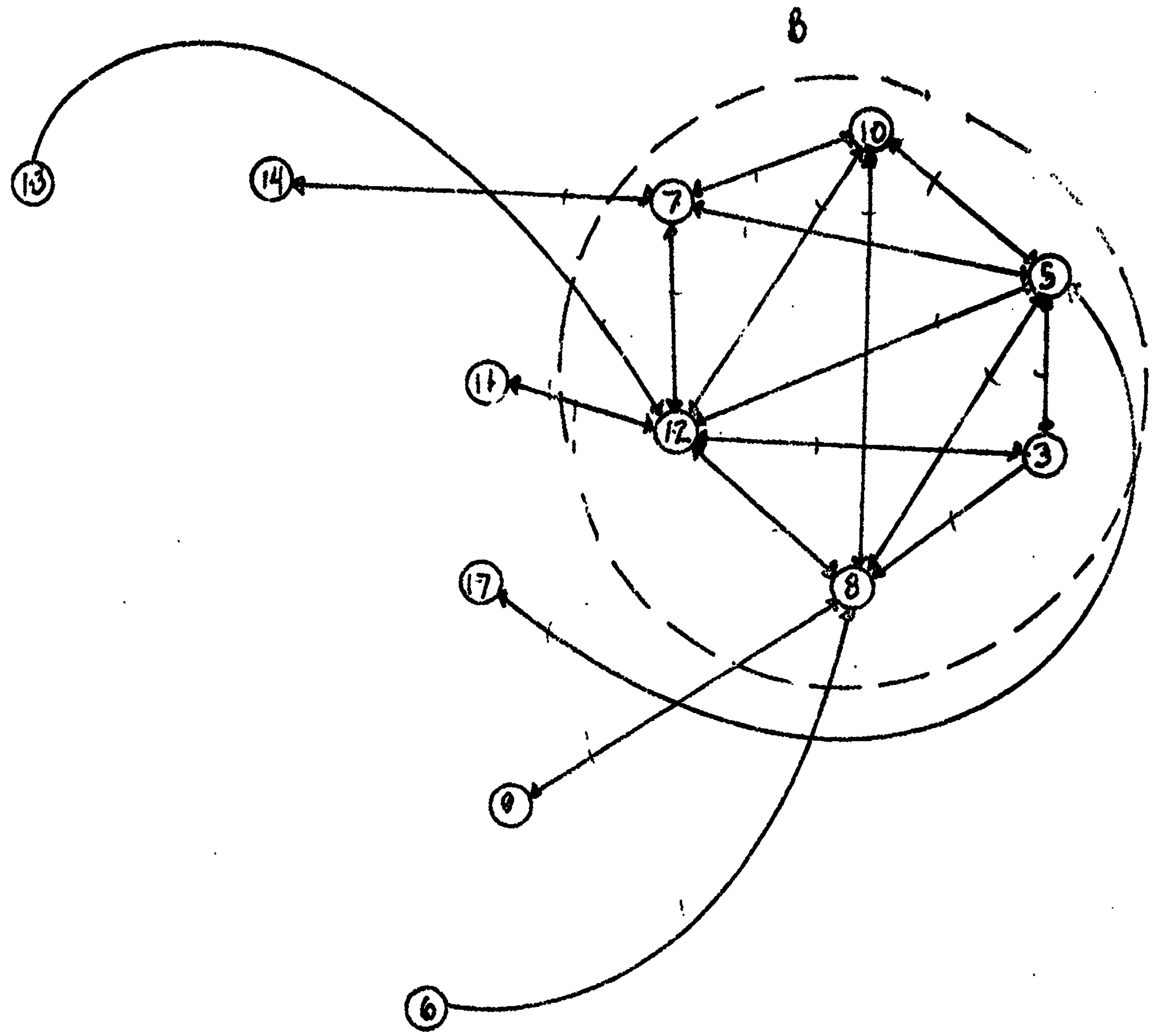


FIGURE 4. GROUP MEMBERSHIP

THE DIAGRAM ABOVE INCLUDES ALL OF THE CONTACTS FROM THE ORIGINAL SOCIOGRAM (IN FIG. 1.) THAT WERE WITH OR BY MEMBERS OF GROUP "B".

OF A TOTAL OF 18 CONTACTS, ONLY 6 WERE NOT BETWEEN GROUP MEMBERS. OF ALL THE CONTACTS REPORTED, BY MEMBERS OF GROUP B, 89% WERE WITH OTHER GROUP MEMBERS.

IF THE CONTACTS REPORTED BY #12 AND #5 ARE COMPARED, IT IS SEEN THAT THEY INCLUDE MANY COMMON CONTACTS. i.e. #12 LISTS : #5, #3, #7, #8, #10, AND #11
#5 LISTS : #12, #3, #7, #8, #10, AND #17

12 AND # 5 HAVE 4 SHARED CONTACTS

AT THE SAME TIME, #11, WHO IS NOT A GROUP MEMBER, SHARES ONLY ONE CONTACT WITH ANY GROUP MEMBER.

SUBJECT NUMBER	CONTACTEE NUMBERS
1	4, 13, 17
2	6, 9, 11, 15, 16
3	5, 12
4	1, 11, 13, 14
5	3, 7, 8, 10, 12, 17
6	2, 9
7	5, 10, 12, 14
8	5, 9, 10, 12
9	2, 6, 8, 15, 16
10	5, 7, 8, 12
11	2, 4, 12, 17
12	3, 5, 7, 8, 10, 11
13	1, 4, 14, 16
14	4, 7, 13
15	2, 9, 16, 17
16	2, 9, 13, 15
17	1, 5, 11, 15
18	——

FIGURE 5a. LISTS OF CONTACTEE SUBJECT NUMBERS

THE NUMBERS ON THE LISTS WERE TAKEN FROM THE DIAGRAM IN FIG. 1. IN FIG. 1, PERSON #1 HAS RECIPROCATED CONTACTS WITH #4, #13, AND #17; #2 WITH #6, #9, #11, #15, #16, AND SO ON FOR ALL 18 PEOPLE.

FIGURE 5b. COMPARISON OF DISTRIBUTIONS

#3 AND #10 ARE IN THE SAME GROUP. #2 IS IN A DIFFERENT GROUP. THE MEAN OF #3'S CONTACTEE NUMBERS IS: $\frac{5+12}{2} = 8.5$. THE MEAN FOR #10 IS: $\frac{5+7+8+12}{4} = 8.0$

SIMILARLY, THE MEAN FOR #2 IS: $\frac{6+9+11+15+16}{5} = 11.2$.

OBVIOUSLY, #3'S MEAN, 8.5, IS CLOSER TO #10'S 8.0 THAN TO #2'S 11.2.

compared. If they are similar, the people are probably in the same group. A simple way to compare two distributions is to compare the means of those distributions. Thus, if two people have similar means, they probably have similar distributions and therefore they probably have pretty much the same contacts, and are thus in the same group (see Figure 5b).

This procedure works well only when all the people in any one group talk only to other people also in that group. However, this is often not the case. In many instances, individuals may have contacts with people outside their group. This can throw a person's mean off enough to make it different from the means of all the other members of his group. To solve this problem and to make the sorting process more efficient and accurate, a weighting process is used that gives more emphasis to those contacts that are with people inside the group than with those outside the group.

Previously, it was pointed out that there would be more two-step links between people in the same group than with people in different groups. Thus, the number of two-step links (shared contacts) is suggested as possibly the ideal weighting factor, since this number is both a valid discriminator and easily calculated (Figure 6a). The mean then would be replaced by a "weighted mean" formed by taking the sum of the products of a person's contactees' subject numbers and the weighting factors, and dividing this sum by the sum of the weighting factors. i.e.,

$$MEAN_I = \frac{I + \sum_{J=1}^{N} WF_{i,j} \cdot CN_j}{1 + \sum_{J=1}^{N} WF_{i,j}}$$

, where WF_{ij} is the weighting factor for the I-J contact; CN_J is the subject number of person J on I's list of contactees; and N is the number of contactees

d

SUBJECT NUMBER	CONTACTEE NO.	WEIGHTING FACTOR	C.N.	W.F.	C.N.	W.F.	C.N.	W.F.	C.N.	W.F.	C.N.	W.F.	C.N.	W.F.	SUM OF W.F.'S	WEIGHTED MEAN
1	4	2	13	2	17	1									5	8.66
2	6	2	9	4	11	1	15	3	16	3					13	11.00
3	5	2	12	2											4	7.40
4	1	2	11	1	13	3	14	2							8	9.33
5	3	2	7	3	8	3	10	4	12	5	17	1			18	9.10
6	2	2	9	2											4	5.60
7	5	3	10	3	12	3	14	1							10	9.27
8	5	3	9	1	10	3	12	3							10	8.90
9	2	4	6	2	8	1	16	3	16	3					13	9.28
10	5	4	7	3	8	3	12	4							14	8.20
11	2	1	4	1	12	1	17	1							4	9.20
12	3	2	5	5	7	3	8	3	10	4	11	1			18	7.31
13	1	2	4	3	14	2	16	1							8	7.88
14	4	2	7	1	13	2									5	9.16
15	2	3	9	3	16	3	17	1							10	10.27
16	2	3	9	3	13	1	15	3							10	9.72
17	1	1	5	1	11	1	16	1							4	9.80
18	—	—														

FIGURE 6a. WEIGHTING FACTORS

FOR EACH CONTACT LISTED BY EVERY PERSON THERE IS A WEIGHTING-FACTOR. IT IS CALCULATED BY COUNTING THE NUMBER OF RECIPROCATED CONTACTS SHARED BY THE TWO PEOPLE. FOR EXAMPLE: THE WEIGHTING FACTOR FOR PERSON #1'S CONTACT WITH #4 IS 2. THIS NUMBER WAS ARRIVED AT BY COMPARING #1'S LIST OF CONTACTEE NUMBERS, #4, #13, AND #17, WITH #4'S LIST, #1, #11, #13, AND #14. THE NUMBER 13 APPEARS IN BOTH LISTS. SINCE THEY LIST EACH OTHER, THE WEIGHTING FACTOR IS 1+1 = 2.

FIGURE 6b. WEIGHTED MEANS

THE WEIGHTED MEAN WAS DEFINED AS:

$$MEAN_I = \frac{I + \sum_{J=1}^{p} (W.F._{IJ} \cdot CN_J)}{1 + \sum_{J=1}^{p} WF_{IJ}}$$

THUS THE MEAN FOR #3 IS CALCULATED:

$$\frac{3 + (2 \times 5) + (2 \times 12)}{1 + 2 + 2} = 7.40$$

THIS NUMBER IS CALCULATED FOR ALL SUBJECTS, EXCEPT ISOLATES, WHO HAVE NO CONTACTS.

person I has.(see Figure 6b). If the weighted mean for each person in the sample is computed, and this list of means is rank ordered, people with similar distributions will be placed near each other.

Two problems are inherent with this method. One is that it is possible for the means of two quite dissimilar distributions to be the same, causing people who are not at all like each other to be put near each other after rank-ordering the means.

The other problem is that, for large organizations and random assignments of subject numbers, there will be high variances for the distributions of most people, even with the weighted means. For example: For an organization of 300 people, a person could have contactee numbers ranging anywhere from 001 to 300. This high variance implies that the means will not be uniquely characteristic of the distributions. In spite of these facts, there will be a better placement of people following the rank-ordering than before it (see Figure 7).

If this ordering process is repeated several times, each time replacing the old subject number of each person with his rank in the ordered list of means, there will be a convergence to a solution for the system. This solution will be an ordering of people in the sample so that those who talk to each other are next to each other (Figure 7b). This ordering will be such that all the people in any one group will be very close to each other, and the variances of the distributions will be minimized. If the data are put in the form of a binary matrix, as described earlier, the non-zero entries will be clustered about the major diagonal; that is, the distance from the diagonal to the non-zero entries will be minimized (see Figure 8).

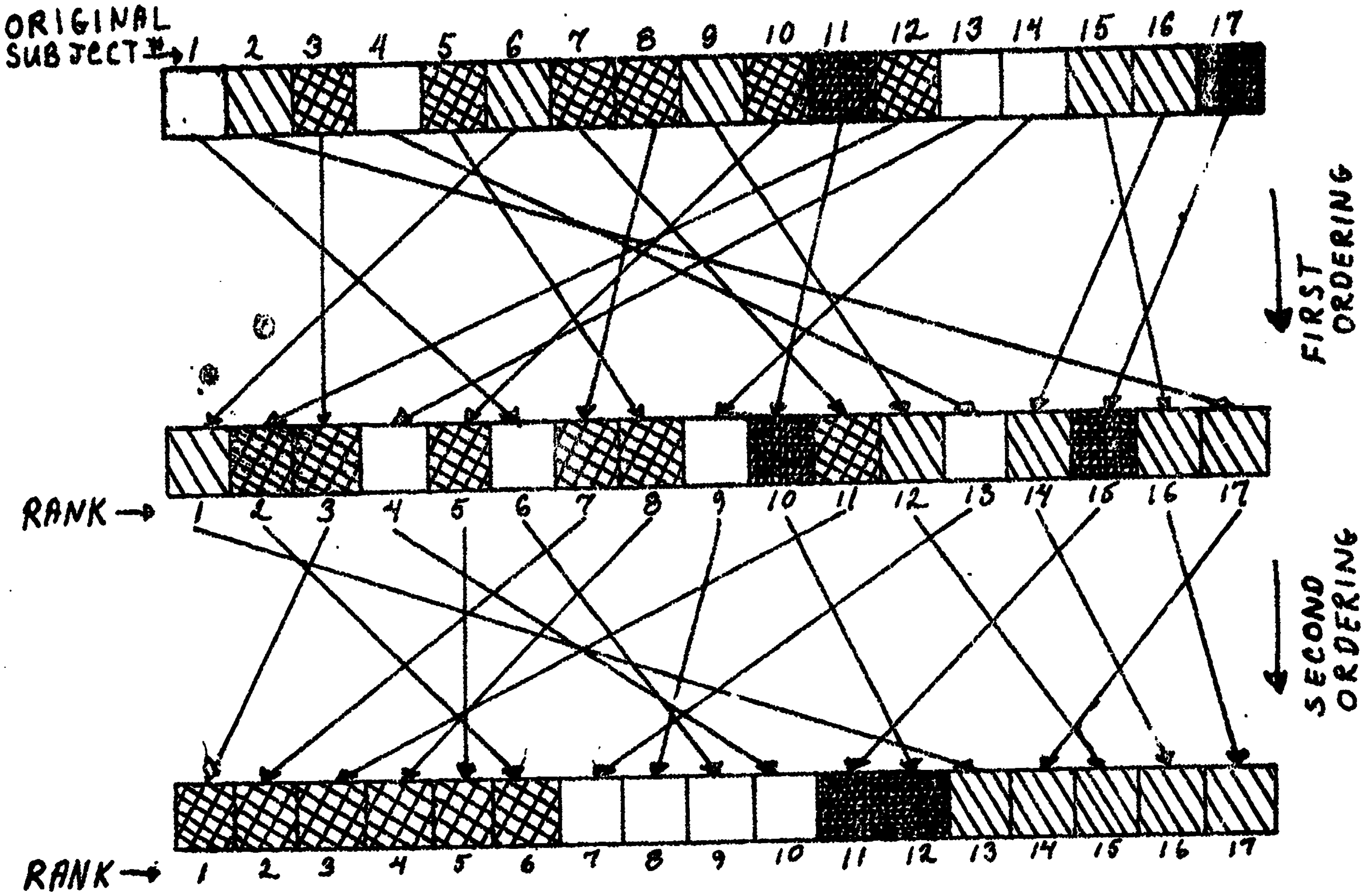


FIGURE 7. EFFECTS OF RANK ORDERING

A. THE FIRST ROW OF THE DIAGRAM ABOVE SHOWS THE INITIAL ORDERING OF THE SAMPLE. THE BLOCKS ARE SHADED DIFFERENTLY TO INDICATE THE GROUP TO WHICH EACH INDIVIDUAL BELONGS.

☐ INDICATES GROUP A. ▨ GROUP B. ▧ GROUP C.

■ INDICATES A LIAISON AGENT.

B. THE SECOND AND THIRD ROWS INDICATE THE ORDERINGS OF THE PEOPLE AFTER THE FIRST AND SECOND CALCULATIONS OF WEIGHTED MEANS. IT CAN CLEARLY BE SEEN IN THE THIRD ROW HOW THE GROUP MEMBERS ARE PUT NEXT TO OTHER MEMBERS OF THE SAME GROUP.

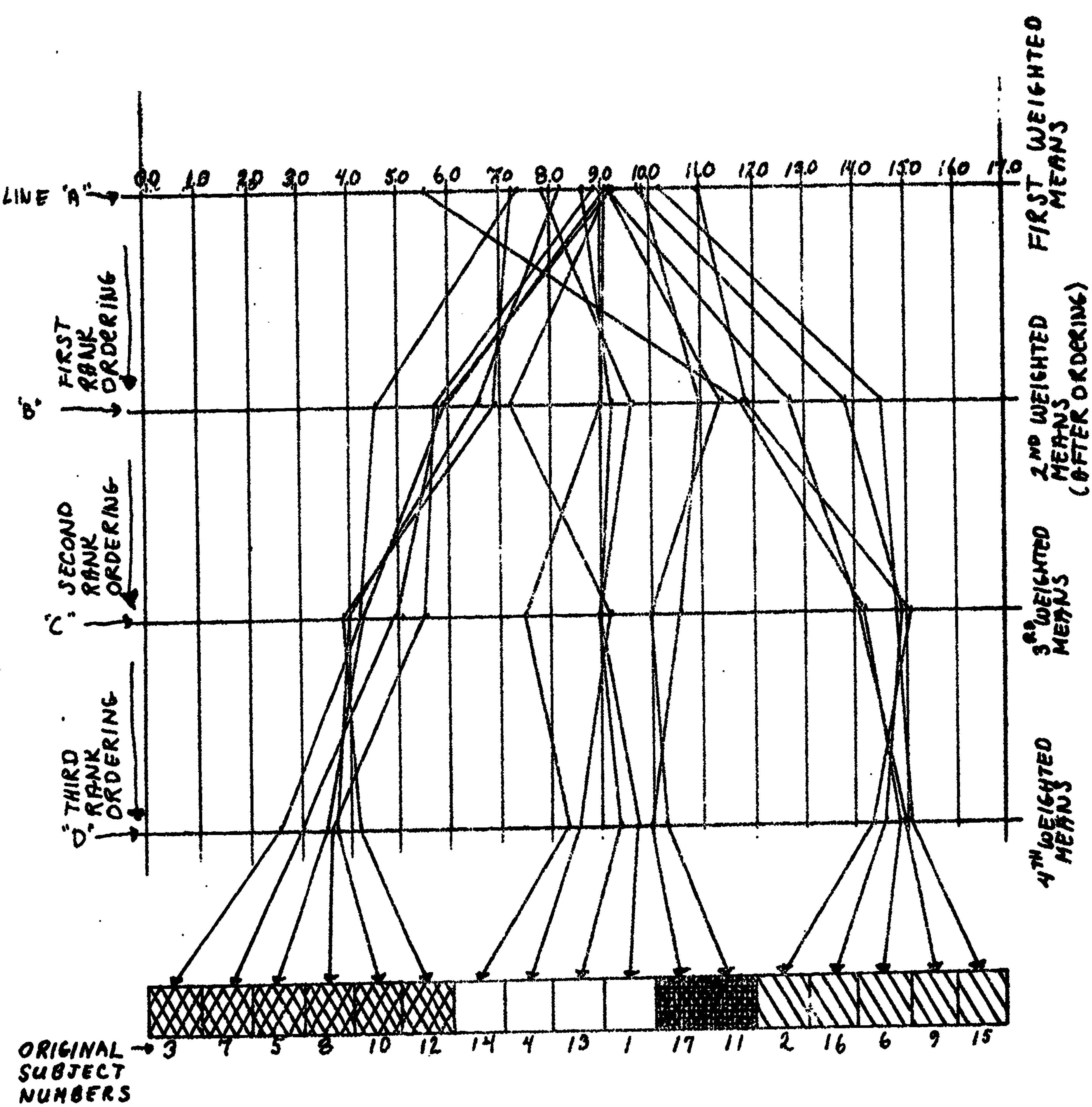
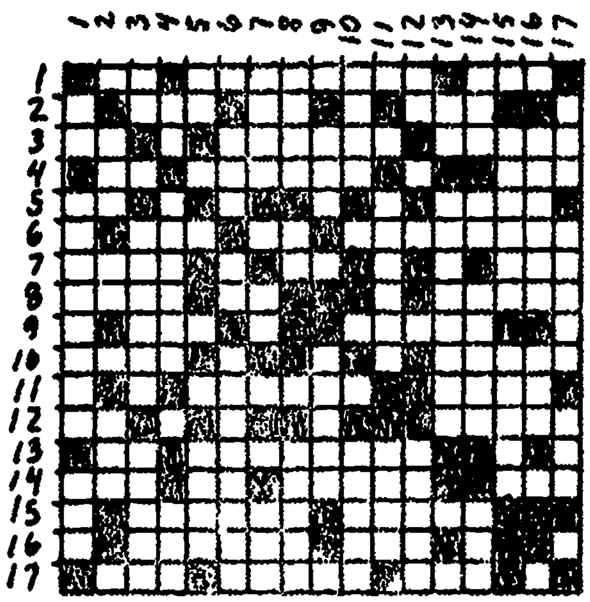
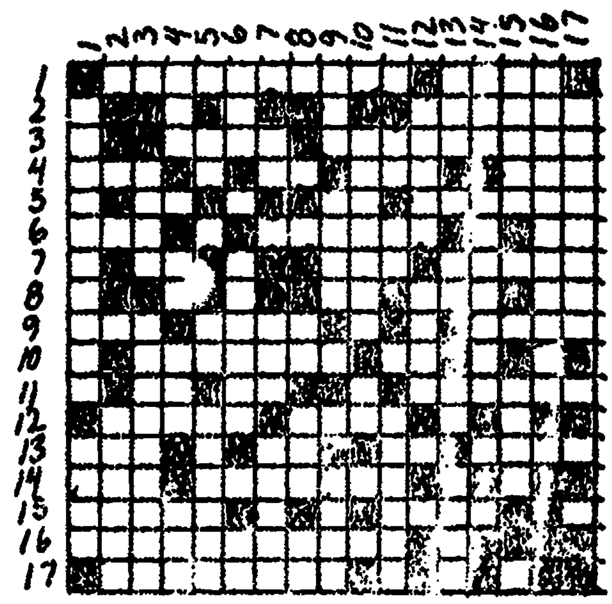


FIGURE 7 B EFFECTS OF SEVERAL ITERATIONS

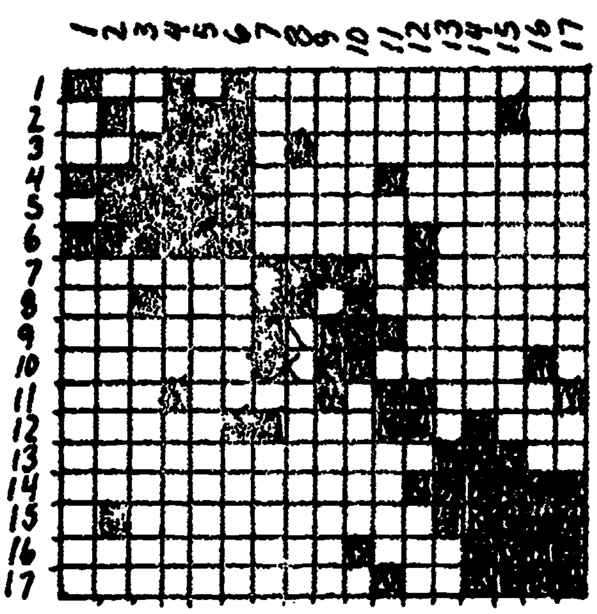
THE POINTS ON LINE "A" ARE THE WEIGHTED MEANS CALCULATED FROM THE ORIGINAL SUBJECT NUMBERS. NOTE HOW THEY ARE CLUSTERED RATHER CLOSELY ABOUT THE CENTER OF THE CONTINUUM. AFTER THESE MEANS ARE RANK-ORDERED, A SECOND RANK ORDERING IS PERFORMED. USING THE RESULTING RANKS AS REPLACEMENTS FOR THE SUBJECT NUMBERS, THE MEANS ARE RE-CALCULATED, RESULTING IN THE POINTS ON LINE "B". BY THE SAME PROCESS THE POINTS ON LINE "C" AND "D" ARE FOUND. A FINAL RANK-ORDERING IS PERFORMED, RESULTING IN THE LAST ROW OF BLOCKS.



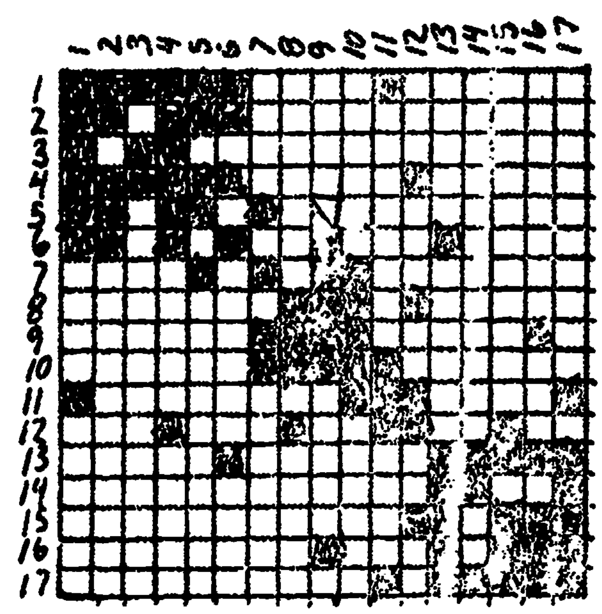
ORIGINAL MATRIX



1ST RE-ORDERED MATRIX



2ND REORDERED MATRIX



3RD RE-ORDERED MATRIX

FIGURE 8. DATA FOR FIRST THREE ITERATIONS IN MATRIX FORM

THE FIRST MATRIX CONTAINS THE ORIGINAL DATA. THE SECOND MATRIX WAS FORMED FROM THE FIRST BY SIMULTANEOUSLY RE-ORDERING THE COLUMNS AND ROWS TO CONFORM TO THE RANKINGS OF THE WEIGHTED MEANS FOR THE ORIGINAL DATA.

SIMILARLY, THE OTHER MATRICES WERE FORMED FROM THE PRECEEDING ONES BY THE SAME KIND OF MANIPULATIONS.

The ordering process is thus composed of these steps: a weighted mean is calculated for each person; these means are rank-ordered, resulting in the assignment of a rank number to each person; old contactee numbers are replaced by the new rank numbers; a test for convergence is made; and the process is either terminated or repeated (see Figure 9).

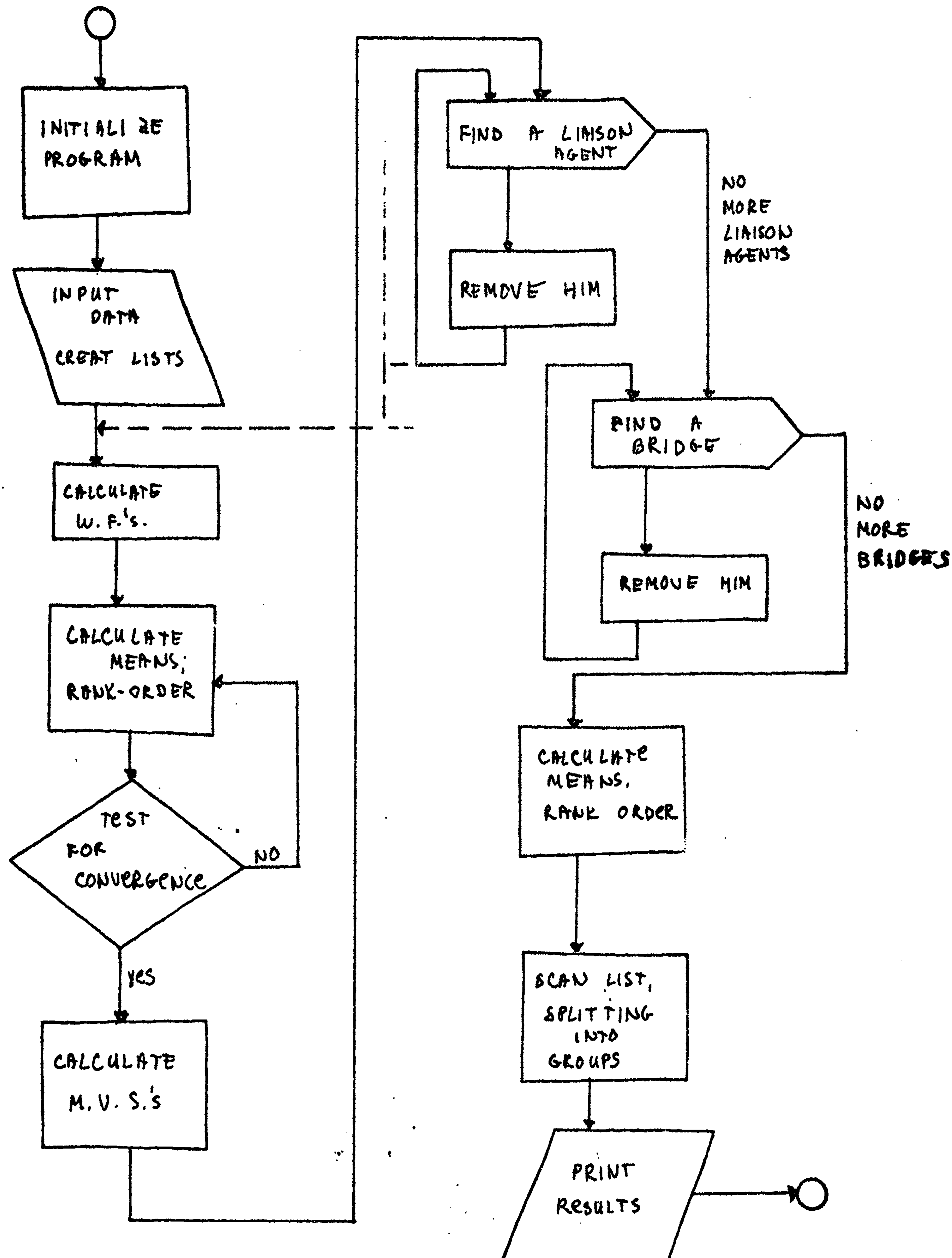
The convergence test could be based on any of several criteria. Two possible limits are: if the variance for each person's updated distribution of contactee numbers (CN's) is calculated, and then all the variances are summed, a measure of the total variance is obtained. If this total variance no longer decreases from one iteration to the next, the solution has converged. A simpler test would be to see if the rank numbers (RN's) change from one iteration to the next. When they no longer do, convergence is complete.

It may not be necessary to reach absolute convergence before proceeding on to the next step in the analysis. For this reason a convergence criteria might be "when less than 5% (10%, 2%) of the ranks change from one iteration to the next, stop."

Identification of Liaison Individuals

Liaison agents must then be identified. Since, by definition, liaison agents talk to people in different groups, their distributions of contactees will be widely dispersed in the rank-ordered lists. A very characteristic aspect of their distributions will be relatively high degrees of variance. An important consideration should be given to the use of variance as a measure of "liaison-agent-ness". A person with many contacts may have a relatively high variance, even if all of his contacts are with people in one group. It would be advantageous, then, to use a measure of variance relative

FIGURE 9 FLOW CHART FOR THE PROCESS



to the lowest possible variance for this number of contacts. In other words, the lowest possible variance for any given individual's distribution, based on the number of contacts he has, could be calculated and subtracted from his actual variance, giving what might be called a modified variance score (MVS). For people whose contacts are restricted to one group, the variance will be close to the lowest possible variance for their distributions. Thus, their MVSs will be very small. For liaison agents, however, the difference between the actual variance and the smallest possible variance will be large, and this will be reflected in the high MVSs. This modification will make it much easier to identify potential liaison agents by providing a more sensitive measure of the spread of each person's distribution (see Figure 10a).

Bridge agents will also have higher degrees of variance than other people. However, they have primary membership in specific groups, whereas liaison agents do not. A method for distinguishing between liaison agents and bridge agents, based on this difference is therefore suggested: A bridge agent belongs to a group. He talks to several members of his group. Most of his contactees talk to the same people he talks to. There are several two-step links between him and his contactees.

A liaison agent, however, talks to people in several different groups, none of which he belongs to. There are few two-step links between him and his contactees, because they are all in different groups. Therefore, he is different from his contactees.

The same numbers used earlier to weight entries in the means can be used here as an index of this "sameness" for a person and his contactees. It can be used to identify liaison agents and separate them from bridge agents (see Figure 10b).

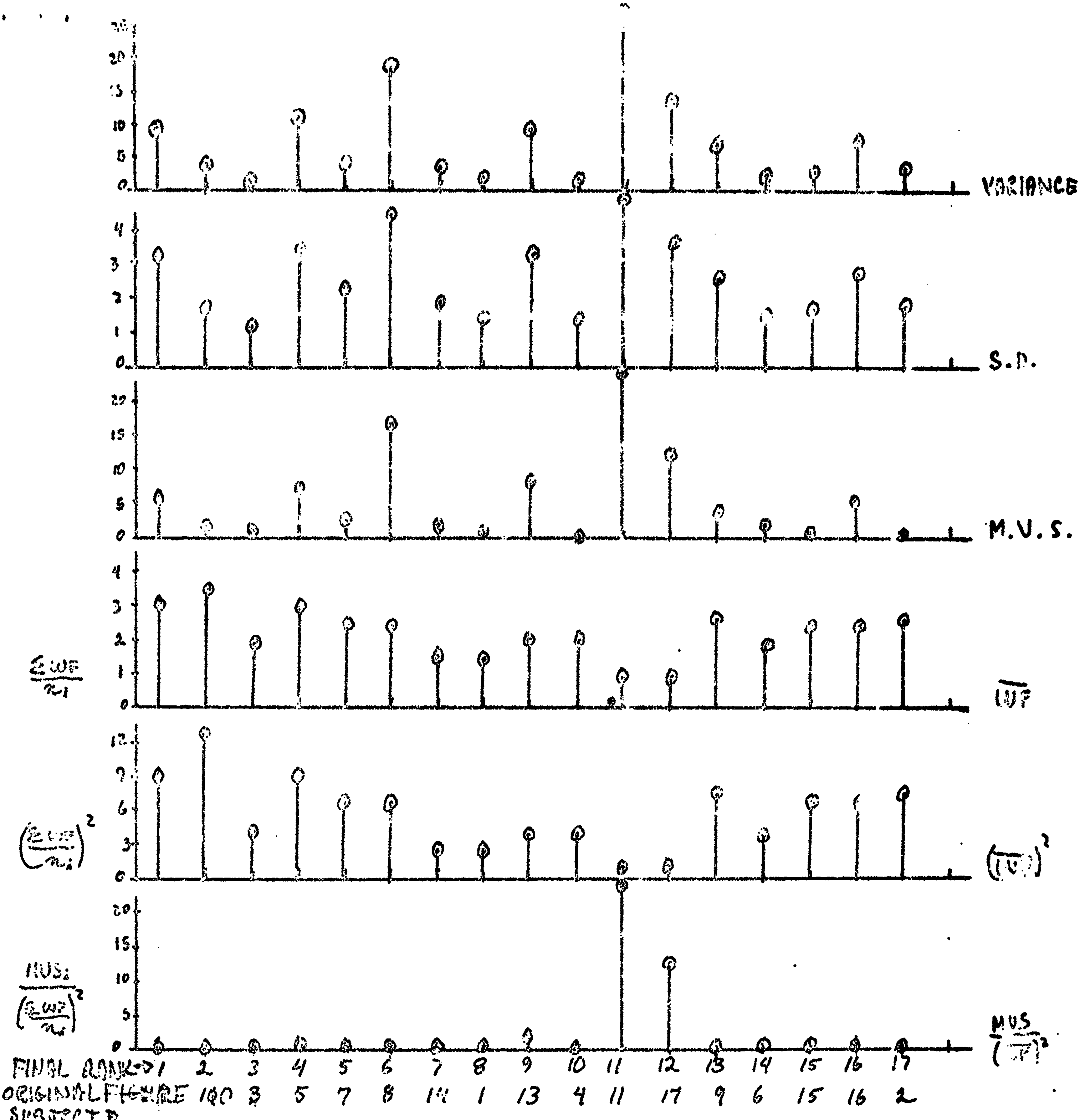


FIGURE 10 A) VARIANCE AND MUS

THE FIRST ROW DIAGRAMS THE VARIANCE OF EACH PERSON'S DISTRIBUTION OF CONTACTS. THIS CAN BE COMPARED WITH THE SECOND AND THIRD ROWS. THE THIRD, WITH MUS'S, IS A BETTER DISCRIMINATOR OF LIAISON AGENTS THAN THE FIRST TWO.

B) THE THIRD ROW CONTAINS THE MEAN W.F. FOR EACH PERSON. WHEN SQUARED AND COMBINED WITH MUS'S, IN ROW 6, ONLY THE LIAISON AGENTS HAVE NUMBERS GREATER THAN 2.

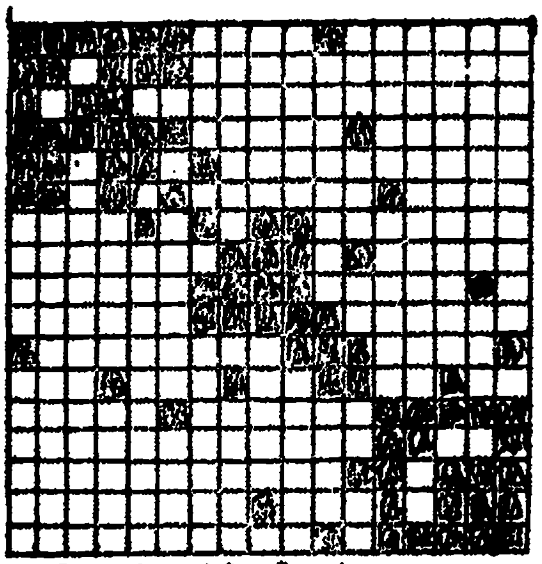
The following process is thus suggested for identifying liaiscn agents and bridge agents:

Calculate the MVS for each person's distribution of CNs. Scan the list of MVSs, searching for the largest. Examine this person's weighting factors (WFs), to determine whether he is a liaison agent or a bridge agent. If he is a liaison agent, remove him from the system and continue searching for more liaison agents.

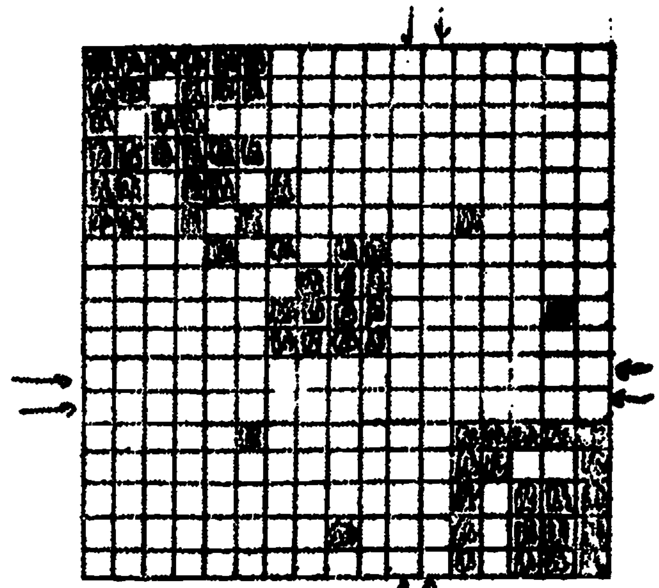
After the removal of several liaison agents, the list of CNs may be considerably changed. For this reason the ordering process should be applied from time to time, say, every 5th (2nd, 10th) liaison agent. When no more liaison agents are left, the bridge agents are identified. To make the following steps easiest and more clear-cut, whenever a bridge agent is identified, a notification is made and the bridge contact is deleted from the appropriate lists. This will leave only those people who belong to groups; and the groups will effectively be isolated from one another (see Figure 11).

Separating the Small Groups

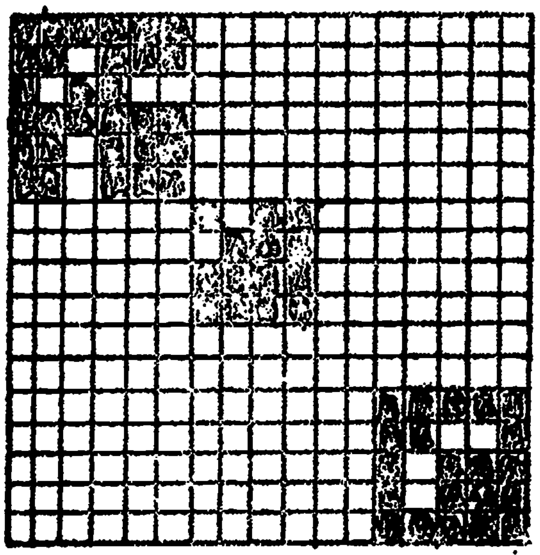
The next step in the analysis is to separate the small groups from each other. If the liaison agents are removed from the lists, it becomes easier to separate the groups, because the list will contain only people belonging to these groups; and because those people sharing membership in the same groups will be placed next to each other in the list. Then, for all the people in any one group, the differences between their weighted means will be relatively small, compared to the differences between their means and those of people in other groups. All that must be done to separate the groups, then, is to scan the rank-ordered list, searching for pairs of adjacent people whose means are very different from each other. The boundaries are located at these points (see Figure 12).



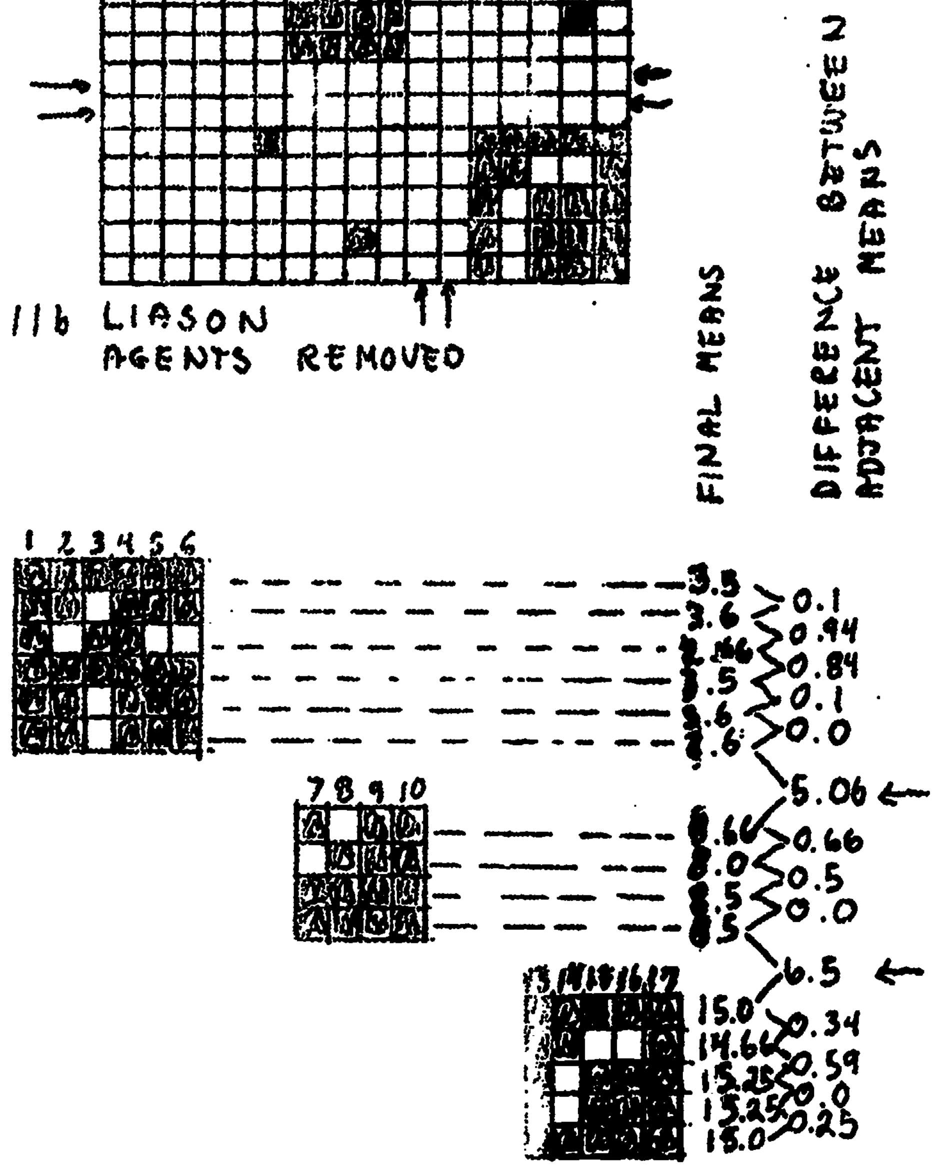
11a FINAL MATRIX



11b LIASON AGENTS REMOVED



11c BRIDGE CONTACTS DELETED



12 SEPARATED INTO SUB-MATRICES

FIGURE 11 REMOVING LIAISON AGENTS AND BRIDGE CONTACTS

THE MATRIX IN THE UPPER LEFT IS THE FINAL MATRIX FROM THE ORDERING PROCESS. AFTER REMOVING LIAISON AGENTS THE UPPER RIGHT MATRIX REMAINS. THE BRIDGE CONTACTS ARE THEN DELETED, GIVING THE MATRIX AT LOWER RIGHT.

FIGURE 12. THE SEPARATED MATRIX

THE FINAL MEANS ARE SHOWN NEXT TO THIS MATRIX, TOGETHER WITH THE DIFFERENCES BETWEEN ADJACENT PAIRS. ALL DIFFERENCES ARE LESS THAN ONE, EXCEPT THE TWO BETWEEN GROUPS.

This concludes the analysis of the communication structure. The following section is concerned with the reduction of computation time and data manipulation, so that the process might be completed more efficiently.

COMPUTER RELEVANT CONSIDERATIONS

For most efficient application of this method, the data should be structured, rather than in a matrix, which will typically have from fifty to ninety percent zeros, in the form of a series of lists. Each person will have a list of the subject numbers of his contactees. These lists will be referenced many times during the process and for this reason a list processing language might seem appropriate for computerization of the process. However, because of the tremendous number of calculations to be made, and the relative slowness of these functions in list processing languages, the ideal language seems to be one like FORTRAN-IV.

To cut computation and data manipulation time, a few labor-saving devices are suggested:

Rather than changing every CN in every list to a new RN every time a rank-ordering is completed, two parallel lists are set up. One contains the original CNs. The other contains the RNs. The latter list is updated after each rank-ordering, and is used to reference the lists of old CNs, much like an index is used to reference the chapters and pages in a book.

Many long lists of numbers have to be rank-ordered in the course of the analysis. The usual method for rank-ordering a list of numbers is to scan the list, searching for the smallest number, then the second-smallest, and so on. For a list of n elements this requires up to $n^2/2$ comparisons to be made. The following alternative method could be used for long lists: Assume a list of up to 999 elements. The largest number has three digits. If the list is sorted into ten piles, by the digit in the one's column, and then again on the ten's column, and finally on the hundred's column, it will be rank-ordered. Only 3n operations will have been performed. For a list of 900 elements, there is a saving of roughly 38,000 operations.

The solution obtained on convergence might not be the best possible solution. This is because no proof of the unique best solution has to this date been formulated. Katz (1958) attempted to form a basis for the proof of this best solution, which he called the canonical form of the matrix (Forsyth and Katz, 1946). The present author feels that such a search, while not irrelevant, should not be considered essential to the creation of a workable method of analysis. In trial applications of the method it was found that it was not necessary to continue the iterative process of ordering the matrix until absolute convergence was reached. This is because the separating methods were sensitive enough to be able to discriminate between liaison agents and others without absolute convergence. For this reason, an "almost absolute" criterion is suggested.

There are several points in the analysis which require specification of threshold values. Several trial runs are now in progress to determine the best values for these levels. It is conceivable that no "best" values will be found. This is due to the nature of the data. For example, the level of connectivity of the organization, measured by the number of non-zero entries in the binary matrix, relative to the highest possible number, would appear to have a great influence on the rapidity of convergence, as well as the relative numbers of liaison and bridge agents. These and several other related problem areas must be studied empirically before specifications can be made.

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